90-6-104

On-Refuge

BOWDOIN NATIONAL WILDLIFE REFUGE
CONTAMINANT BIOMONITORING
STUDY

Progress Report

FFS# 198960003.3

90-6-104

By

Kristi DuBois

U.S. Fish and Wildlife Service
Helena, Montana

April 1990

2

BOWDOIN NATIONAL WILDLIFE REFUGE

CONTAMINANT BIOMONITORING STUDY, 1989

INTRODUCTION

Contamination of wetlands by selenium and other trace elements from agricultural drainage water has been documented in California and other western states (Ohlendorf and Skorupa 1989). Elevated levels of several trace elements were found on the Bowdoin National Wildlife Refuge (NWR) during a U.S. Department of the Interior reconnaissance study (Lambing et al. 1988). Lake Bowdoin water had elevated boron concentrations. The Dry Lake Unit had elevated water concentrations of arsenic, uranium, and vanadium. Dry Lake sediment contained twice as much chromium, zinc, copper, nickel, and vanadium as background levels in surrounding soils. Boron residues in two American Coot (*Fulica americana*) livers (140 µg/g dry weight), sago pondweed (*Potamogeton pectinatus*; 810 µg/g) and plankton (750 µg/g) were at levels associated with adverse reproductive effects in birds (Patuxent Wildlife Research Center 1987). Selenium residues in some samples of plankton (13 µg/g) and macroinvertebrates (6.5 µg/g) were near selenium dietary doses known to cause reproductive problems in Mallards (Heinz et al. 1987).

The purpose of this study was to determine the extent of trace element contamination, particularly boron and selenium, and organochlorine contamination in sediment and biota at Bowdoin National Wildlife Refuge.

3

Specific objectives were to:

1) **Determine contaminant loads in adult waterbirds (American Avocet (*Recurvirostra americana*), American Coot, Eared Grebe (*Podiceps nigricollis*), dabbling duck species, and diving duck species) upon their arrival at the refuge in spring.**

2) Determine possible impacts on waterbird production by examination of embryos for deformities and analysis of eggs for contaminant levels.

3) **Determine contaminant levels in young-of-the-year waterbirds prior to their fledging and departure from Bowdoin.**

4) **Evaluate potential food chain contamination by determining contaminant residues in bottom sediment, aquatic plants and aquatic invertebrates.**

STUDY AREA DESCRIPTION

PHYSICAL SETTING

Bowdoin National Wildlife Refuge (Figure 1), located 11 km east of Malta, Montana, was established in 1936. The 6337 ha refuge lies in the Central Flyway, and is managed primarily as a breeding and staging area for migratory

4

waterfowl. A system of dikes and ditches was built in 1936 to manage the water levels. An annual water right of 3,500 acre-feet (4,317,211 m^3) from the Bureau of Reclamation's Milk River System supplements natural run-off, providing a reliable source of water. Ground-water seeps and irrigation drainage from adjacent farmlands contribute small quantities of water to the refuge.

WATER SYSTEM

The Refuge has four main water units (Lake Bowdoin, Drumbo, Lakeside, and Dry Lake) and several small ponds (Figure 2). During years of limited water supply, there is no outflow of water and the refuge becomes a closed evaporation basin. Under such water-deficient conditions, the lakes and ponds recede to low levels as a result of evaporation. When water levels in Lake Bowdoin are high, water drains from Lake Bowdoin and Dry Lake into Beaver Creek. When Beaver Creek floods, water from Beaver Creek discharges into Lake Bowdoin and Dry Lake.

Leakage of water from the Dodson Canal contributes to the formation of extensive saline seeps along the northwest shore of Lake Bowdoin (Figure 1). Natural saline seeps and alkali flats are found on other areas of the Refuge. The relative contributions of salts in the refuge water units from natural saline seeps, leakage from the Dodson Canal, irrigation drainage, precipitation run-off from the watershed, and inflow from the Dodson Canal are unknown.

CLIMATE

The climate of Bowdoin NWR is semiarid continental, which is characterized by cold, dry winters; warm, dry summers, and low annual precipitation. Mean annual precipitation is 32.3 cm (12.72 in), most of which occurs as rain from April to July. The area has experienced drought for most of the last 10 years (1980-81, 1983-84, and 1987-89). Mean annual air temperature is about 6 °C (42 °F). Average monthly temperatures range from about -13 °C (8 °F) in January to 21 °C (70 °F) in July. Seasonal extremes in temperature can range from near -51 °C (-60 °F) in winter to about 43 °C (110 °F) in summer.

Weather during the sampling year was dryer than normal, resulting in low water levels in Lake Bowdoin and many of the smaller ponds. The Dry Lake Unit was dry, with the exception of the northwest bay which is diked off from the main unit (referred to as Dry Lake Pond). The water levels in Lakeside, Teal Ponds, Dry Lake Pond, and Drumbo were supplemented by water from the Dodson Canal during July and August.

HABITAT

Upland habitats make up 48% of the Refuge (3048 ha) and are dominated by arid mixed-grass native prairie (2707 ha, 89% of the uplands). Other upland habitats are inland saline flats, introduced grasslands, Dense Nesting Cover (DNC), shelterbelts and shrub areas, and administrative lands such as roads

and dikes. Introduced grasslands and DNC are being allowed to revert back to native prairie. No farming or livestock grazing are currently practiced on the refuge. Land surrounding the refuge is dominated by dryland and irrigated farming, and livestock production.

Wetlands cover 52% of the Refuge (3289 ha). Saline marshes comprise 2767 ha (84%) of these wetlands. Other wetland types are fresh water marshes and seasonally flooded basins or flats.

Emergent aquatic vegetation in the water units is dominated by hardstem bulrush (Scirpus acutus), broadleaf cattail (Typha latifolia), and alkali bulrush (Scirpus paludosus). Submergent aquatic vegetation is dominated by sago pondweed (Potamogeton pectinatus). Other species of pondweed are present in lesser amounts (P. filiformis, P. zosteriformis, and P. perfoliatus. Other common aquatic submergents are Northern watermilfoil (Myriophyllum exalbescens) and widgeongrass (Ruppia maritima).

Increasing salinity of some of the water units over the years has decreased the extent of emergent vegetation in Lake Bowdoin, and resulted in the replacement of cattails by hardstem bulrush in some areas (G. Sipe, pers. commun.).

7

WILDLIFE RESOURCES

Over 225 bird species and 29 mammal species have been identified at Bowdoin National Wildlife Refuge. The Refuge lies within the Central Flyway, and hosts up to 100,000 ducks, geese, shorebirds, and other waterbirds during spring and fall migration. Large colonies of colonial birds nest on the islands in Lake Bowdoin, including American White Pelicans (Pelecanus erythrorhynchus), Great Blue Herons (Ardea herodias), Double-crested Cormorants (Phalacrocorax auritus), Black-crowned Night-herons (Nycticorax nycticorax), White-faced Ibises (Plegadis chihi), Eared Grebes, American Avocets, Franklin's Gulls (Larus pipixcan), California Gulls (Larus californicus), and Ring-billed Gulls (Larus delawarensis).

Piping Plovers (Charadrius melodus), Bald Eagles (Haliaeetus leucocephalus), and Peregrine Falcons (Falco peregrinus) have been observed on the refuge, but no nesting has been documented.

Duck Production

Duck production at Bowdoin National Wildlife Refuge declined from about 20,000 birds in 1961 to about 3,000 in 1986 (G. Sipe, pers. commun.). Duck production in 1989 was estimated at about 1,700 (D. Prellwitz, pers. commun.). This decline is consistent with declines in duck breeding populations across the Prairie Pothole Region in the U.S. and Canada. Possible factors contributing to duck population declines are habitat loss, drought, increased predation, disease, lead poisoning, and decreased water quality. Water levels at Bowdoin National Wildlife Refuge fluctuated widely during the 1980's, ranging from severe flooding to severe drought. This was suspected to be the major cause of declining Bowdoin duck populations during recent years (G. Sipe, pers. commun.).

METHODS

SAMPLE COLLECTION

Sediment, plant, and invertebrate samples were collected from twelve sites, including several sites in Lake Bowdoin, and the Lakeside, Lakeside Extension, Farm Pond, Farm Pond Extension, Teal Pond, Goose Island Pond, Dry Lake Pond, Drumbo, and Patrol Road Pond units (Figure 3). Only sediment was collected from the main Dry Lake Unit (Site #12), which was dry.

Sediment samples were collected by hand and placed in either plastic sample jars (for inorganic contaminant analysis) or acid-washed glass jars (for organic contaminant analysis). Plant samples, consisting mainly of leaf/stem parts, were collected and placed in acid-washed glass jars. Invertebrate composite samples were collected with light traps (Espinosa and Clark 1972) or a sweep net, sorted by order or family with forceps, and placed in acid-cleaned jars. A minimum of 8 g was collected for plant and invertebrate samples, and 100 g for sediment samples. All samples were stored frozen until shipment for chemical analysis.

Samples of sago pondweed and algae were collected from sample sites #1-#11. Algae samples consisted mainly of filamentous green algae, but were not identified to species.

Aquatic invertebrate samples included daphnia (Order Cladocera, Family Daphnidae), amphipods (Order Amphipoda), damselfly nymphs (Order Odonata, Suborder Zygoptera), waterboatmen (Order Hemiptera, Family Corixidae), midge larvae (Order Diptera, Family Chironomidae), and aquatic beetle larvae (Order Coleoptera). No aquatic invertebrates were collected from Patrol Road Pond (Site #11), due to insufficient invertebrate populations, or from Dry Lake (Site #12) which was dry.

Daphnia and waterboatmen were collected from all sites, except Sites #11 and #12. Daphnia samples from Teal Pond (Site #4) and Goose Island Pond (Site #5) also contained small, black water mites, which were difficult to sort from the daphnia. The daphnia sample from Dry Lake Pond (Site #9) contained small, orange unidentified zooplankton, possibly <u>Cyclops</u> or a related copepod.

Midge larvae were collected from Sites #1-#10. The midge larvae sample from Site #7, which consisted of only 3.3 g, was not submitted for chemical analysis. Amphipods were collected from Sites #4, #7, and #8. Damselfly nymphs were collected from Sites #1, #3, #5, and #7. Aquatic beetle larvae were collected from Sites #4, #5, and #8. The amphipod, damselfly nymph, and aquatic beetle larvae samples were not sent in for analysis. They will be submitted later, if the results from other samples indicate a possible contamination problem.

10

The waterbird species targeted for adult bird, egg, and young-of-the-year collections were the American Avocet, American Coot, Eared Grebe, Northern Shoveler (*Anas clypeata*), and Ruddy Duck (*Oxyura jamaicensis*). Egg samples were also collected from Gadwall (*Anas strepera*) nests, due to their abundance on the refuge.

Five adult waterbirds of each target species were collected during May with 12 or 20 gauge shotguns and steel shot. Their livers were removed and frozen in acid-cleaned jars. Body fat samples were collected from adult birds for organochlorine and PCB analysis by scraping subcutaneous fat with forceps. The fat was stored in acid-cleaned jars and frozen. We attempted to collect at least 8 g of fat from each individual bird, but we pooled fat samples from two individuals when necessary to get an adequate sample. The American Avocets did not have enough fat to be scraped off for a sample. Their carcasses were plucked, wrapped in aluminum foil, and frozen in Whirlpak plastic bags. One Eared Grebe body fat sample consisted of a composite from two individuals. The other waterbird fat samples were from individual birds. Gizzards were removed from adult birds and frozen in acid-washed glass jars. They will be analyzed in the future to determine food habits if the chemical analyses indicate high contaminant levels.

Waterbird nests were located and marked using several methods. Nests of American Avocets, American Coots, Eared Grebes, and Ruddy Ducks were located by searching suitable nesting habitat by wading, or by canoe or airboat. Upland duck nests were located and marked by cable-chain dragging (Klett et al. 1986) as part of the annual duck nesting survey at the refuge. Nests were marked with plastic flagging and monitored until hatching. One egg was collected from each nest for trace element analysis, and an additional egg from some nests for organochlorine pesticide analysis. We attempted to collect eggs that were at least halfway through incubation, to provide embryos large enough to examine for abnormalities. Incubation stage of the nests was determined by candling the eggs from upland duck nests (Klett et al. 1986) and floating the eggs from other species (Westerskov 1950). Intact eggs remaining in hatched, abandoned, or predated nests were also collected for examination. These eggs were saved for chemical analysis as needed to complete the proposed sampling for a species, or if gross visual examination indicated possible contamination.

Eggs were opened with a scalpel and their contents emptied into a glass Petri dish. Fertility, viability, and observable gross abnormalities were noted. Embryo age was estimated using photographic keys for Mallards (Caldwell and Snart 1974) and Wood Ducks (*Aix sponsa*; Burke et al. 1978), with adjustments for differences in incubation periods. The egg contents were then placed into acid-cleaned glass jars, weighed and frozen.

Young-of-the-year waterbirds were collected with shotguns and steel shot or picked up during botulism searches. Young birds were collected just prior to fledging, to make certain that they were produced at the refuge and had not migrated in from outside areas. Livers were removed, weighed, and preserved for chemical analysis by freezing in acid-cleaned jars. The carcasses were wrapped in aluminum foil and frozen in Whirlpak plastic bags.

12

SAMPLE ANALYSIS

We submitted 197 samples for chemical analysis including 180 for inorganic trace element analysis, and 40 for organic contaminant analysis. The types and locations of the samples are listed in Table 1. Sixteen gizzard samples from adult waterbirds, and 23 hatch-year waterbird carcasses were preserved (frozen) to provide additional information on food habits and body condition of individual birds with high levels of contaminants.

Samples analyzed for inorganic trace elements included 12 sediment, 22 aquatic plant, 29 aquatic invertebrate, 69 waterbird egg, and 47 waterbird liver samples. Selenium and arsenic concentrations were determined by hydride generation atomic absorption spectroscopy. Mercury was analyzed by cold vapor atomic absorption spectroscopy. Other elements were analyzed using the inductively coupled plasma-atomic emission spectrometric method (ICP scan).

Samples analyzed for organic contaminants included 4 sediment, 16 waterbird fat (or carcass), and 20 waterbird egg samples. Samples were analyzed for organochlorines and polychlorinated biphenyls (PCBs) using a gas chromatograph equipped with dual capillary column/dual electron capture detector.

Laboratory quality control was assured through the Patuxent Analytical Control Facility (PACF). The precision and accuracy of the laboratory analyses are confirmed with procedural blanks, duplicate analyses, test recoveries of

13

spiked material, and reference material analyses. Round-robin tests among U.S. Fish and Wildlife Service (USFWS) and contract analytical labs also are part of the PACF quality assurance review. All USFWS contaminant analyses receive a PACF quality assurance review.

RESULTS AND DISCUSSION

WATERBIRD NESTING SUCCESS

American Avocet

A total of 16 American Avocet nests were located and marked in 1989. Nest initiation for 15 monitored nests ranged from 19 May to 18 June, with most nests initiated from 21-28 May. Several other avocet nests in one colony were hatching on 13 June, indicating they were initiated on approximately 17 May. Fifteen eggs were collected from eleven nests (Figure 4). Twelve eggs were submitted for trace element analysis and three eggs were submitted for organochlorine analysis. Four additional eggs were picked up from three terminated nests with unknown histories, two from an abandoned clutch, and two from nests of unknown fate. These four eggs were opened in the lab to look for abnormalities, but were not submitted for chemical analysis. No abnormalities were observed in any of the avocet embryos examined.

14

Ten avocet nests were known or suspected to have hatched, and 7 nests were unsuccessful, for an apparent nest success of 59%. Nest success of American Avocets was difficult to determine, due to the absence of evidence in the nest bowls. Avocet young stay in the nest long enough after hatching to trample the eggshell remains. Nests with a few eggshell fragments without membranes attached were assumed to be successful. Unsuccessful nests were determined by evidence such as predator tracks leading to a nest bowl without any eggshell fragments, eggshell fragments with membranes attached in the nest, the absence of observations of adults in the vicinity of nests that should have been attended, and nests which were found empty before the estimated hatching date (determined by aging embryos in the eggs collected).

Nine of the sixteen monitored nests were located on small islands in Lake Bowdoin, Lakeside, or Dry Lake Pond. Eight of these nests were successful. The other seven nests were located on saline seep areas along the north shore of Lake Bowdoin or between the Drumbo Unit and Big Island (Figure 4). These nests were accessible to terrestrial predators. Five of these were unsuccessful, and two hatched.

No American Avocet young were collected. Fledging success appeared to be poor, although no quantitative data were gathered. A few newly-hatched young were observed June 13 on the three islands in Lake Bowdoin which harbored a total of 120 avocet nests. No live young were observed on these islands during a return visit on July 12. No partly-grown avocet young were observed while conducting other field work during early summer. When we tried to collect avocet young in mid-July, any that had been present had fledged and

15

were difficult to distinguish from molting adults. The reasons for the apparent lack of avocet young are not known. One dead avocet chick (newly-hatched) was observed on the nesting islands. It was too decomposed to collect for necropsy.

American Coot

We collected American Coot eggs from most of the main water units, due to the wide distribution and high nesting population of coots. Twenty-three coot nests were marked, and eggs were collected from 18 of them (Figure 5). Nest initiation for 22 monitored nests ranged from 10 May to 7 July. Most of the July nests were unsuccessful renesting attempts. Seventeen eggs were submitted for trace element analysis and three eggs were submitted for organochlorine analysis. No abnormalities were observed in 15 coot embryos examined.

Coot nest success was difficult to determine. American Coots are known commonly to eat or remove the eggshells and membranes from nests after the young hatch (Fredrickson 1970). Most coot nests examined contained only a few eggshell fragments or nothing at all. Some coot nest platforms were flooded or were covered by muskrat activity. Based on the limited evidence at nest sites, 8 coot nests were suspected to have hatched, and 8 nests were unsuccessful, for an apparent nest success of 50%. A number of coot nests in the Lakeside Unit were flooded during incubation when water levels were manipulated. Only one of these nests (#C11) was flagged, but apparently many of the coots tried to renest, as evidenced by the appearance of newly-

16

initiated coot nests in the vicinity of flooded nest platforms. Coot nest #C11 was flooded a second time, shortly after initiation of the second nest attempt. Coot nests in Goose Island Pond did not appear to be flooded from the water manipulations that occurred there. The eggs of several other marked coot nests disappeared before the estimated hatching dates, indicating predation or abandonment followed by scavengers.

American Coot nest #C01 in Goose Island Pond contained a clutch of 11 infertile eggs. This nest was in mid-laying when first located. Eggs were collected on three visits, after the clutch should have been about half-way through incubation. All three eggs were infertile and rotten. During the fourth visit, the eggs remaining in the nest were covered by egg yolk from an egg which had exploded. The broken egg had been removed by the coot, and was floating in the water next to the nest. A fourth egg collected during this visit exploded while being measured in the lab. The coot attending the nest was present during all nest visits, and aggressively defended the nest with "swanning" and "churning" behaviors (Ryder 1959). The eggs were warm during each nest visit. On the last visit, the coot nest was estimated to have been incubated for approximately 27 days. One egg from this nest was submitted for inorganic analysis.

Hen success of American Coots appeared to be good, as many coot hens attempted to renest after the loss of their clutches. Coot broods were common on the refuge, and were the dominant waterfowl species at several small ponds. Five young-of-the-year coots were collected (Figure 5).

Eared Grebe

Eared Grebe nesting colonies were located in Lake Bowdoin ($\geq$1,000 nests), Drumbo (about 200 nests), and Lakeside (about 50 nests). Nest initiation for 13 marked nests ranged from 11 June to 21 June, although newly-initiated nests were observed through late July. Eared Grebe eggs were collected from 10 nests in the large Lake Bowdoin colony and 3 nests in the Drumbo colony (Figure 6). No embryonic abnormalities were observed, but one Eared Grebe egg (#EG11) had an abnormal yolk which was marbled with egg white. This egg was submitted for trace element analysis. Thirteen eggs (10 from Lake Bowdoin and 3 from Drumbo) were submitted for trace element analysis and three eggs (all from Lake Bowdoin) were submitted for organochlorine analysis.

Nest success of marked Eared Grebe nests was impossible to determine. Several nests in the large Lake Bowdoin colony were apparently unsuccessful and replaced by second nests, as evidenced by newly-laid eggs present when the nests should have hatched. Some nest platforms had disappeared by the second nest visit. Intact nest platforms had no visible evidence, such as eggshells, indicative of the nest fate.

Observations of Eared Grebe broods indicated that rates of nest failure and chick mortality were probably fairly high. Numerous abandoned eggs remained in the Lake Bowdoin nest colony, after hatching was completed. Few Eared Grebe young were observed, compared to the large numbers of nests in the colonies. We collected five Eared Grebe young in Lake Bowdoin (Figure 6).

18.

Northern Shoveler

Five adult Northern Shovelers were collected during May for liver and body fat samples (Figure 7). Eleven shoveler nests were found during nest dragging, and eggs were collected from seven of them (Figure 7). Nest initiation for 10 shoveler nests ranged from 18 May to 3 June. One nest was crushed by our nest-dragging vehicle, and three nests were destroyed by predators before eggs were collected. One successful shoveler nest contained three eggs with dead embryos, two 8 days old and one 22 days old. Two of these were submitted for chemical analysis. Two other dead eggs remaining in this nest appeared to be infertile. Another shoveler nest contained an egg which had died at 8 days. None of the shoveler embryos from live or dead eggs had any visible abnormalities. Four ducklings examined in a nest during hatching also appeared normal. Nine shoveler eggs were submitted for trace element analysis and four eggs were submitted for organochlorine analysis.

Six of the eleven shoveler nests were successful, for an apparent success rate of 55%. Predation by mammals was the most common cause of nest loss.

Nine shoveler young were collected, one by steel shot and 8 during botulism checks (Figure 7). Four of the young were probably brood siblings. They were picked up near each other on the same day, along with an adult shoveler in the Drumbo Unit.

19

Gadwall

Eggs were collected from 10 Gadwall nests (Figure 8) to provide a better sample of dabbling duck eggs. The Gadwall was the most abundant nesting duck species during 1989. Nest initiation for 10 marked gadwall nests ranged from 1 June to 12 June. No embryonic deformities were observed. Eggs with dead embryos were collected from two nests. One embryo had died at 8 days, the other at 20 days. Both were submitted for analysis.

Apparent nest success was 71% for 17 gadwall nests observed. No adult or young Gadwalls were collected.

Ruddy Duck

Five adult Ruddy Ducks were collected during May (Figure 9). In spite of their early arrival on the breeding areas, Ruddy Ducks did not initiate nesting at Bowdoin until mid-summer (23 June to 27 July). By that time, falling water levels had rendered much of the potential nesting habitat useless. Ruddy Ducks are late nesters, due to their preference for nesting in tall, green emergent vegetation instead of standing cover from the previous year's growth (Siegfried 1976).

Eight Ruddy Duck nests were located during nest searches on the Refuge (Figure 9). All were in hardstem bulrush patches, over water ranging from 0.3-1 meters (1-3 feet) deep. Ruddy Duck eggs were collected during the first nest visit, regardless of the incubation stage, due to the difficulty of finding and re-visiting their nests.

None of the marked Ruddy Duck nests was successful. Two (or possibly three) of the nests on Drumbo were suspected to be nesting attempts from the same hen (R01, R06, and R08). These nests were within 30 meters (100 feet) of each other, and temporally spaced. All three nests were unsuccessful due to abandonment or predation, two before clutch completion and one early in incubation. Three nests on Lake Bowdoin were apparently destroyed by predators, as evidenced by shell fragments with membranes attached. Another Ruddy Duck nest in Lake Bowdoin was abandoned, with a dead White-faced Ibis (*Plegadis chihi*) chick lying on top of the eggs. The only nest found in Lakeside was abandoned when found.

In spite of the poor nest success of monitored Ruddy Duck nests, 2 young were collected from a brood on Teal Pond, and 2 young were collected during botulism patrols on Drumbo (Figure 9). The secretive behavior of Ruddy Duck broods made it difficult to locate and collect young.

21

White-faced Ibis

One White-faced Ibis egg was collected from a nesting colony in Lake Bowdoin (Figure 10). It came from a nest which also contained the badly decomposed remains of a newly-hatched chick. Dead partly-grown White-faced Ibis chicks were observed in at least seven nests during a visit to the colony on 14 July. They were too decomposed to be collected for necropsy.

Piping Plover

Two Piping Plover (Charadrius melodus) eggs were collected from a nest at Nelson Reservoir which was destroyed by flooding. The nest was first located on 2 June, on a small island near the northwest shore of Nelson Reservoir (T. 32 N., R. 32 E., Sec. 22), approximately 29 km northeast of Malta. The nest, which contained 4 eggs, was only 1 m from the edge of the water, and only about 6 cm elevation above the water. A pair of plovers were present and attending the nest.

The nest was flooded by rising water levels, when checked on 5 June. About 2 cm of water covered the nest bowl, half-covering the two eggs which remained. The other two eggs had either been washed away or scavenged. A mat of algae partly surrounded the eggs, and the nest was now about 10 cm from the water's edge. No adult plovers were observed in the area. The remaining eggs were not collected until 7 June, after verification of a permit to do so. The water had risen another 2-4 cm, and the eggs had floated out of the nest bowl, but were within 30 cm of it. A pair of plovers were present and defensive of the island. They later attempted unsuccessfully to renest.

The Piping Plover eggs contained embryos which were estimated to be about half-way through incubation (approximately 12 days old). They were pooled into one sample, in order to have a sample weight greater than 8 g. The sample was submitted for organochlorine and PCB analysis.

TRACE ELEMENTS IN SEDIMENT AND BIOTA

Sediment

Ranges and geometric mean trace element concentrations for sediment samples collected in 1989 are listed in Table 2. All trace element concentrations are reported as µg/g (ppm) dry weight. Levels from 1989 did not appear to differ significantly from 1986 levels, with the exception of boron, which was more than ten times higher in 1989 than in 1986 (Table 3). Levels of lead, mercury, and selenium were slightly higher in 1989 than in 1986. Comparison of sediment residue values for these two years can only be qualitatively interpreted, because different sample locations were used during the 1986 and 1989 studies.

Bowdoin 1989 geometric means (Table 3) for selenium and boron were more than twice the U.S. western geometric means (WGM) for these elements (Shacklette and Boerngen 1984). All of the 1989 Bowdoin sediment samples contained boron levels higher than the WGM. Goose Island Pond, Dry Lake Pond, Dry Lake Main Unit, and three of the Lake Bowdoin sediment samples contained boron levels of 100 µg/g or higher in 1989. The highest boron level (151 µg/g from the northwest shore of Lake Bowdoin) was below the observed western maximum of 300 µg/g. Two sediment samples (Drumbo and Lake Bowdoin East) did not have detectable levels of selenium. All other sediment samples contained higher selenium levels than the WGM. Sediment samples from Lake Bowdoin West and Teal Pond contained more than 1 µg/g selenium (Figure 11), but these levels were well below the observed western maximum of 4.3 µg/g.

In 1989, geometric mean concentrations of arsenic, barium, chromium, copper, and mercury in sediment were at or below the western geometric mean concentrations (Table 3).

Aquatic Plants

Most trace element concentrations in algae and sago pondweed samples were below dietary concentrations believed to be harmful to waterfowl (Table 2). Algae from Patrol Road Pond contained 29 µg/g arsenic. Arsenic levels of 30 µg/g in the diet caused decreased growth rates in ducklings (Patuxent Wildlife Research Center 1987) in laboratory studies. Arsenic levels in all other aquatic plant samples ranged from 1-14 µg/g.

Sago pondweed from Dry Lake Pond contained 1060 µg/g boron. Mallards fed 1,000 µg/g dietary boron laid eggs which suffered significantly lower hatching success (Smith and Anders 1989). Four out of eleven algae samples and nine out of eleven sago pondweed samples had boron levels greater than 300 µg/g. Smith and Anders (1989) found that dietary boron levels of 300 µg/g caused no significant reproductive problems in Mallards. Boron levels in aquatic plants did not appear to correlate with boron levels in sediment collected in the same water unit.

Selenium levels in aquatic plants ranged from <0.3-1.07 µg/g, well below dietary levels shown to cause reproductive problems in Mallards (Heinz et al. 1987). Selenium levels in aquatic plants did not appear to correlate with selenium levels in sediment collected in the same water unit.

Geometric mean trace element concentrations of arsenic, boron, and zinc were higher in 1989 than in 1986 (Table 4) in algae, but not sago pondweed. Chromium levels in both algae and sago pondweed were significantly lower in 1989 than in 1986. Trace element concentrations in 1989 samples were generally similar to or below concentrations in the 1986 samples for other elements analyzed in both years (Table 4).

Aquatic Invertebrates

Geometric mean trace element concentrations in invertebrates were generally below dietary levels known to be harmful to waterfowl (Table 2). A daphnia sample from the Drumbo Unit contained the highest level of arsenic (7.1 µg/g), which was well below the level of 30 µg/g believed to be harmful to ducklings (Patuxent Wildlife Research Center 1987). Boron levels were also well below

25

levels known to cause reproductive problems in ducks (Smith and Anders 1989). Aquatic invertebrate samples from the north and west shores of Lake Bowdoin generally had higher boron levels in all three species of aquatic invertebrates than samples from other areas. All of these areas also had sediment samples with greater than 100 µg/g boron. Boron levels were also relatively high in aquatic invertebrates from the Drumbo unit, which had only 52 µg/g boron in sediment. Thus, the dissolved concentration of boron in water may also be an important factor in determining the amount of boron accumulated by aquatic invertebrates. Daphnia and midge larvae had higher boron levels than waterboatmen (Table 2).

Mercury levels in two waterboatmen samples (0.397 µg/g and 0.469 µg/g) and one daphnia sample (0.397 µg/g) were slightly below dietary levels of 0.5 µg/g fed to adult Mallards which caused behavioral changes in their ducklings (Heinz 1975). These levels were well below mercury concentrations of 3 µg/g associated with lower hatching success in Mallards (Heinz 1974). Two of these samples were from Teal Pond, and the third was from Farm Pond. Both Teal Pond and Farm Pond had sediment mercury concentrations higher than all other units except Dry Lake Pond. The mercury level in Dry Lake Pond sediment was more than twice the levels in Teal or Farm Ponds, yet aquatic invertebrate samples from Dry Lake Pond contained fairly low levels of mercury.

All aquatic invertebrate samples had selenium levels below dietary concentrations of 10 µg/g known to cause elevated levels of embryo abnormalities in Mallards (Heinz et al. 1987). Midge larvae contained more selenium than waterboatmen or daphnia (Table 2). The three highest midge larvae samples were from Goose Island Pond (4.9 µg/g), Lake Bowdoin-West shore (5.3 µg/g), and Lake Bowdoin-NW shore (5.4 µg/g).

Trace element concentrations in waterboatmen collected in 1989 were similar to concentrations in Hemiptera samples (consisting of both waterboatmen and back striders [Notonectidae]) collected in 1986 (Table 4). Only one midge larvae sample was collected in 1986, from the north end of Lake Bowdoin. It contained higher levels of aluminum (8700 µg/g), arsenic (2.4 µg/g), boron (160 µg/g), chromium (17 µg/g), iron (4300 µg/g), nickel (12 µg/g), tin (100 µg/g, and vanadium (11 µg/g) than the highest 1989 midge larvae samples. Other trace elements in the 1986 sample were within the ranges of the 1989 samples. Since only one midge larvae sample was collected in 1986, it is not known if the higher levels were representative of general conditions in 1986, or specifically related to the 1986 sample location.

<u>Waterbird Adults</u>

Trace element concentrations in 25 adult waterbird livers generally were low or not detectable (Table 5), with the exception of selenium. Liver selenium levels in 2 American Avocets, 1 Eared Grebe, and 1 Ruddy Duck were above 30 µg/g. The highest selenium level was 61 µg/g, in an American Avocet collected along the northwest shore of Lake Bowdoin. These selenium levels are comparable to levels found in waterbirds that suffered high levels of embryo death and deformities at Kesterson NWR in California (Ohlendorf and Skorupa 1989). Selenium levels in the livers of 10 other adult birds collected at

Bowdoin were above 9 µg/g. Selenium concentrations in waterbird livers from freshwater habitats normally range from 4-9 µg/g (Eisler 1985, Ohlendorf and Fleming 1988, Ohlendorf 1989).

In laboratory studies on Mallards, liver selenium levels took about 8 days to plateau after starting a diet with 10 µg/g selenium (Heinz et al. in press). After selenium treatments stopped, liver selenium levels dropped by 50% in 19 days. The adult avocets at Bowdoin were collected on 2 May. The average arrival date for American Avocets at Bowdoin NWR is 18 April (data from 1979 to 1983, D. Prellwitz, pers. commun.), allowing the possibility that the avocets picked up the selenium after arriving at Bowdoin.

Waterbird eggs

Trace element concentrations in 69 waterbird eggs analyzed were either not detectable or below levels that would indicate reproductive impairment (Table 6). Mean selenium levels were highest in Eared Grebes and lowest in American Coots. Normal selenium concentrations in eggs range from 1 to 3 µg/g dry weight (Ohlendorf 1989). Selenium levels at Bowdoin were greater than 3 µg/g in 1 Northern Shoveler, 1 Ruddy Duck, 3 American Avocet, and 12 Eared Grebe eggs. The highest selenium level was 6.4 µg/g in an Eared Grebe egg, compared to a mean of 69.7 µg/g in Eared Grebe eggs at Kesterson NWR (Ohlendorf and Skorupa 1989). Selenium levels in avocet eggs ranged from 1.8 to 4.3 µg/g, in spite of high selenium levels in some adult avocets. This indicates possibly: 1) the adult avocets collected on 2 May had accumulated selenium elsewhere, and had eliminated most of it by 17 May when nesting was initiated, 2) the adult avocets collected were migrants that picked up the selenium elsewhere, and nested somewhere else, or 3) some of the avocets at Bowdoin are accumulating selenium from localized areas on the refuge, and no nests from contaminated adults were sampled.

Trace element concentrations in the dead/addled eggs did not appear to differ from levels in eggs which were alive when collected. Inorganic contaminant levels probably did not cause the embryo deaths observed in coot egg #C01, grebe egg #EG11, or any of the other addled eggs collected. Trace element concentrations in eggs collected in 1989 did not appear to differ significantly from eggs collected in 1986 (Table 4).

SUMMARY

Selenium and boron levels in most sediment samples were higher than the U.S. western geometric means, but lower than the U.S. western maxima.

One algae sample contained arsenic levels nearly as high as dietary levels known to cause harmful effects in ducks. Other algae samples had low trace element concentrations.

One sago pondweed sample had boron levels as high as dietary levels known to cause reproductive problems in Mallards. Other trace element concentrations in sago pondweed were low.

30

FUTURE PLANS

The remaining bird liver samples will be analyzed for trace element residues in FY 90. Future sampling plans will be oriented toward: 1) Evaluating the potential interrelation of selenium on American Avocet productivity, and 2) Trace element analysis and bioassays of shallow groundwater on the north shore of Lake Bowdoin.

Water quality sampling has been conducted at Bowdoin NWR for several years. The water quality data will be entered into a computer database to facilitate monitoring. In addition, discussions will be initiated with the Bureau of Reclamation concerning the feasibility of reducing leakage in the section of the Dodson Canal adjacent to the refuge.

LITERATURE CITED

Burke, C.J., S.M. Byers, and R.A. Montgomery. 1978. A field guide to the aging of wood duck embryos. J. Wildl. Manage. 42(2):432-437.

Caldwell, P.J., and A.E. Snart. 1974. A photographic index for aging mallard embryos. J. Wildl. Manage. 38(2):298-301.

Eisler, R. 1985. Selenium hazards to fish, wildlife, and invertebrates: A synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85 (1.5). U.S. Fish Wildl. Serv., Washington, DC.

Espinosa, L.R., and W.E. Clark. 1972. A polypropylene light trap for aquatic invertebrates. Calif. Fish Game 58(2):149-152.

Fredrickson, L.H. 1970. Breeding biology of American coots in Iowa. Wilson Bull. 82:445-457.

Mercury levels in three aquatic invertebrate samples were only slightly lower than dietary levels which caused behavioral changes in Mallard offspring, but much lower than levels that caused significant reproductive effects. Selenium levels ranged up to 5 µg/g in midge larvae, about one-half the dietary level known to cause reproductive problems in Mallards.

Trace element concentrations in aquatic plants and invertebrates did not correlate consistently with levels in sediment samples collected in the same water unit.

High selenium levels were found in the livers of some American Avocets, Eared Grebes, and Ruddy Ducks. Selenium levels in eggs of the same species were slightly higher than normal levels, but below levels associated with embryonic deformities and mortality. It could not be determined if these waterbirds were accumulating selenium during migration, or after arriving at Bowdoin NWR. It is possible that high selenium levels are a problem in small, local areas of the refuge, and affect only a small proportion of the waterbirds breeding there.

Boron accumulation did not appear to be a problem in waterbirds, in spite of higher than average boron levels in sediment.

No adverse reproductive effects (excessive rates of embryo death, embryonic deformities, etc.) were observed in the waterbirds at Bowdoin NWR. However, fledging success of American Avocets and Eared Grebes appeared to be poor.

Heinz, G.H. 1974. Effects of low dietary levels of methyl mercury on mallard reproduction. Bull. Environ. Contam. Toxicol. 11:386-392.

Heinz, G.H. 1975. Effects of methylmercury on approach and avoidance behavior of mallard ducklings. Bull. Environ. Contam. Toxicol. 13:554-564.

Heinz, G.H., D.J. Hoffman, A.J. Krynitsky and D.M.G. Weller. 1987. Reproduction of mallards fed selenium. Environ. Toxicol. and Chem. 6:423-433.

Heinz, G.H., G.W. Pendleton, A.J. Krynitsky, and L.G. Gold. In Press. Storage and elimination of selenium by mallards. Arch. Environ. Contam. Toxicol.

Lambing, J.H., W.E. Jones, and J.W. Sutphin. 1988. Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in Bowdoin National Wildlife Refuge and adjacent areas of the Milk River Basin, northeastern Montana, 1986-87. U.S. Geologic Survey, Water-Resources Investigations Report 87-4243, Helena, Montana.

Klett, A.T., H.F. Duebbert, C.A. Faanes, and K.F. Higgins. 1986. Techniques for studying nest success of ducks in upland habitats in the Prairie Pothole Region. U.S. Fish Wildl. Serv., Resour. Publ. 158. 24 pp.

Ohlendorf, H.M. 1989. Bioaccumulation and effects of selenium in wildlife. Pages 133-177 in L.W. Jacobs (ed) Selenium in Agriculture and the Environment. SSSA Spec. Publ. No. 23. American Society of Agronomy and Soil Science Society of America, Madison, WI.

Ohlendorf, H.M., and W.J. Fleming. 1988. Birds and environmental contaminants in San Francisco and Chesapeake bays. Mar. Pollut. Bull. 19:487-495.

Ohlendorf, H.M., and J.P. Skorupa. 1989. Selenium in relation to wildlife and agricultural drainage water. Fourth Ann. Int. Symp. on Uses of Selenium and Tellurium; Banff, Alberta, May 1989; proceedings to be published.

Patuxent Wildlife Research Center. 1987. Effects of irrigation drainwater contaminants on wildlife. USFWS Patuxent Wildlife Research Center, Annual Report Fiscal Year 1986. 24 pp.

Ryder, R.A. 1959. Interspecific intolerance of the American coot in Utah. Auk 76:424-443.

Shacklette, H.T., and J.G. Boerngen. 1984. Element concentrations in soils and other surficial materials of the conterminous United States. U.S. Geological Survey Professional Paper 1270, Washington, DC.

32

Siegfried, W.R. 1976. Breeding biology and parasitism in the ruddy duck. Wilson Bull. 88(4):566-573.

Smith, G.J., and V.P. Anders. 1989. Toxic effects of boron on mallard reproduction. Environ. Toxicol. Chem. 6:943 -950.

Westerskov, K. 1950. Methods for determining the age of game bird eggs. J. Wildl. Manage. 14:56-67.

Table 1. Type and number of samples submitted for chemical analysis from each water unit of Bowdoin National Wildlife Refuge and Nelson Reservoir, 1989.

Sample Matrix	Lake Bowdoin	Teal Pond	Goose Island Pond	Drumbo	Lakeside	Dry Lake Pond	Farm Pond	Patrol Road Pond	Main Dry Lake	Nelson Res	Total
Sediment	5	2	1	2	2	1	1	1	1		16
Aquatic Plant											
Algae	4	1	1	1	1	1	1	1			11
Sago Pondweed	4	1	1	1	1	1	1	1			11
Aquatic Invertebrates											
Daphnia	4	1	1	1	1	1	1				10
Waterboatmen	4	1	1	1	1	1	1				10
Midge Larvae	3	1	1	1	1	1	1				9
Adult Waterbird Fat[a]											
American Avocet	2	1									3
American Coot					1		1	1			3
Eared Grebe	3										3
Northern Shoveler					1		3				4
Ruddy Duck	1		1				1				3
Adult Waterbird Livers[a]											
American Avocet	4	1									5
American Coot		1			2		1	1			5
Eared Grebe	4		1								5
Northern Shoveler					2		3				5
Ruddy Duck	2		1		1		1				5
Young Waterbird Livers											
American Coot		2	2					1			5
Eared Grebe	5										5
Northern Shoveler	4			4	1						9
Ruddy Duck		2		2							4
Bird Eggs											
American Avocet	11				2	2					15
American Coot	5		5	3	4		1	2			20
Eared Grebe	13			3							16
Northern Shoveler	13										13
Gadwall	13										13
Ruddy Duck	6			2	2						10
White-faced Ibis	1										1
Piping Plover										1[b]	1

[a] Adult waterbird fat and liver samples were taken from the same 25 birds collected.
[b] Two eggs pooled into one sample.

Table 2. Geometric mean trace element concentrations (µg/g dry weight) in sediment, aquatic plants, and aquatic invertebrates from Bowdoin National Wildlife Refuge, 1989. Ranges are shown in parentheses.

Element	Sediment (n = 12)	Algae (n = 11)	Sago Pondweed (n = 11)	Daphnia (n = 10)	Midge Larvae (n = 9)	Waterboatmen (n = 10)
Aluminum	25195 (6810 - 47900)	1246 (123 - 8250)	196 (<50 - 1740)	1723 (700 - 3600)	1270 (559 - 2450)	143 (50.8 - 562)
Arsenic	3.36 (1.49 - 6.3)	7.96 (3.88 - 29.5)	2.88 (0.953 - 13.1)	4.12 (2.32 - 7.1)	1.01 (0.594 - 1.33)	0.45 (<0.2 - 1.05)
Barium	503 (373 - 638)	53.3 (<5 - 307)	26.1 (7.21 - 109)	35.2 (15.2 - 81.5)	16.8 (6.42 - 53.3)	7.3 (1.94 - 21.3)
Beryllium	0.84 (0.57 - 1.69)	NC[b] (<0.3 - 1.02)	NC (<0.3 - 1.32)	ND[a] (<0.2 - <0.2)	ND (<0.2 - <0.2)	ND (<0.2 - <0.2)
Boron	79.8 (43.6 - 151)	226 (82.6 - 674)	449 (184 - 1060)	22.9 (6.92 - 58.6)	11.2 (6.73 - 29.8)	4.5 (<2 - 13.1)
Cadmium	ND (<1 - <1)	NC (<0.5 - 2.08)	NC (<0.5 - 3.86)	NC (<0.5 - 0.92)	NC (<0.5 - 1.1)	NC (<0.5 - 1.58)
Chromium	38.0 (20.8 - 74.5)	3.5 (<3 - 10.2)	NC (<3 - 4.26)	3.2 (<3 - 5.31)	NC (<3 - 3.19)	ND (<3 - <3)
Copper	16.2 (6.97 - 28.3)	3.2 (<3 - 11.4)	NC (<3 - 6.72)	14.8 (8.18 - 24.1)	14.8 (9.12 - 21.2)	20.5 (11.8 - 43.8)
Iron	19516 (10500 - 35000)	2273 (494 - 9440)	539 (174 - 1910)	2203 (955 - 4750)	2180 (1230 - 3320)	317 (150 - 753)
Lead	19.1 (<11 - 32.1)	NC (<7 - 13.2)	NC (<7 - 18.3)	NC (<5 - 6.79)	NC (<5 - 8.16)	ND (<5 - <5)
Magnesium	5156 (600 - 13700)	9930 (5510 - 53400)	9589 (5350 - 25900)	5934 (3260 - 12900)	2621 (1450 - 5730)	1934 (1110 - 3530)
Manganese	397 (161 - 1220)	988 (82.8 - 23400)	785 (<50 - 16300)	147 (24.7 - 704)	68.6 (16.5 - 320)	44.2 (15.8 - 203)
Mercury	0.046 (<0.02 - 0.153)	0.02 (<0.02 - 0.062)	ND (<0.02 - <0.02)	0.085 (<0.02 - 0.397)	NC (<0.02 - 0.123)	0.159 (0.086 - 0.469)
Molybdenum	ND (<10 - <10)	NC (<5 - 6.23)	NC (<5 - 10.5)	ND (<7 - <7)	ND (<7 - <7)	ND (<7 - <7)

Table 3. Comparison of 1989 geometric mean trace element concentrations (µg/g dry weight) in sediment with 1986 concentrations from Bowdoin National Wildlife Refuge, and U.S. Western Geometric Means. Ranges are shown in parentheses.

Element	1989 Sediment (n = 12)	1986[a] Sediment (n = 6)	U.S. Western Geometric Mean[b]	U.S. Western Maximum[b]
Arsenic	3.36 (1.49 - 6.3)	6.5 (4.7 - 8.6)	5.5	97
Barium	503 (373 - 638)	734 (500 - 940)	580	5,000
Beryllium	0.84 (0.57 - 1.69)	NA[c]	0.68	15
Boron	79.8 (43.6 - 151)	5.7 (1.2 - 27)	23	300
Chromium	38.0 (20.8 - 74.5)	71 (58 - 99)	41	2,000
Copper	16.2 (6.97 - 28.3)	25 (20 - 37)	21	300
Lead	19.1 (<11 - 32.1)	15 (12 - 20)	17	700
Manganese	397 (161 - 1220)	NA	380	5,000
Mercury	0.046 (<0.02 - 0.153)	0.019 (<0.02 - 0.03)	0.046	4.6
Nickel	18.77 (9.27 - 33.8)	25.8 (22 - 37)	15	700
Selenium	0.52 (<0.3 - 1.33)	0.37 (0.3 - 0.6)	0.23	4.3
Vanadium	76 (43 - 155)	90 (70 - 160)	70	500
Zinc	64 (30.4 - 110)	82 (60 - 120)	55	2,100

[a] Lambing et al. 1988.
[b] Shacklette and Boerngen 1984.
[c] NA = Not analyzed.

Table 2. (cont.)

Element	Sediment (n = 12)	Algae (n = 11)	Sago Pondweed (n = 11)	Daphnia (n = 10)	Midge Larvae (n = 9)	Waterboatmen (n = 10)
Nickel	18.77 (9.27 - 33.8)	6.00 (3.58 - 14.8)	NC (<2.5 - 14.5)	NC (<3.5 - 5.82)	ND (<3.5 - <3.5)	ND (<3.5 - <3.5)
Selenium	0.52 (<0.3 - 1.33)	0.36 (<0.3 - 1.07)	NC (<0.3 - 0.75)	1.69 (1.28 - 2.43)	3.57 (1.28 - 5.38)	1.50 (0.71 - 2.95)
Silver	ND (<10 - <10)	ND (<10 - <10)	ND (<10 - <10)	ND (<10 - <10)	ND (<10 - <10)	ND (<10 - <10)
Strontium	240 (87.2 - 875)	242 (70 - 845)	132 (74.9 - 340)	677 (244 - 1450)	40.9 (18.7 - 83.4)	28.6 (14.2 - 63.4)
Tin	NC (<55 - 67)	ND (<40 - <40)	ND (<40 - <40)	ND (<30 - <30)	ND (<30 - <30)	ND (<30 - <30)
Vanadium	76 (43 - 155)	3.9 (<1 - 14.9)	1.9 (<1 - 7.99)	3.6 (<1.5 - 7.83)	3.3 (<1.5 - 5.88)	NC (<1.5 - 1.7)
Zinc	64 (30.4 - 110)	18.4 (10.7 - 52.8)	14.6 (9.1 - 28.8)	87.5 (63.8 - 151)	89.8 (71.3 - 117)	193 (161 - 262)

[a] ND = Not detected.
[b] NC = Not calulable.

37

Table 4. Comparison of geometric mean trace element concentrations (µg/g dry weight) from 1986 and 1989 plant, invertebrate, and waterbird egg samples, Bowdoin National Wildlife Refuge.

	Sago Pondweed		Algae		Hemiptera-Boatmen		American Coot Eggs		American Avocet Eggs	
	1986	1989	1986	1989	1986	1989	1986	1989	1986	1989
Aluminum	1,797	196	2,626	1,246	196	143	NC[a]	NC	3.1	ND[b]
Arsenic	3.0	2.9	4.3	8.0	ND	0.45	ND	NC	ND	ND
Barium	31	26	73	53	5.6	7.3	1.9	2.8	3.0	1.3
Boron	522	449	159	226	NC	4.5	14.1	2.7	NC	NC
Chromium	16.1	NC	51	3.5	6.7	ND	NC	NC	NC	ND
Copper	4.8	NC	4.9	3.2	14.4	20.5	2.9	3.4	2.3	3.1
Iron	3632	539	2261	2273	297	317	103	131	127	124
Magnesium	6575	9589	7140	9930	2075	1934	439	635	383	496
Manganese	520	785	701	988	31	44	NC	3.5	ND	3.6
Mercury	ND	ND	ND	0.02	ND	0.16	0.26	0.34	0.32	0.49
Nickel	10.4	NC	24	6	3.8	ND	NC	ND	NC	ND
Selenium	NC	NC	NC	0.36	NC	1.5	1.4	1.5	2.6	2.7
Strontium	256	132	258	242	30	29	13.5	16.3	8.7	13.6
Vanadium	4.9	1.9	5.6	3.9	ND	NC	ND	ND	ND	ND
Zinc	13.7	14.6	NC	18.4	129	193	43	66	64	51

[a] ND = Not calculable.
[b] NC = Not detected.

Table 5. (cont.)

Element	American Avocet (n = 5)	Eared Grebe (n = 5)	American Coot (n = 5)	Northern Shoveler (n = 5)	Ruddy Duck (n = 5)
Nickel	ND (<1.23 - <1.73)	ND (<1.15 - <1.28)	ND (<1.35 - <1.52)	ND (<1.30 - <1.36)	ND (<1.34 - <1.55)
Selenium	15.4 (6.6 - 61.4)	17.2 (7.2 - 37.1)	5.3 (4.6 - 7.8)	8.6 (4.8 - 13.8)	15.3 (9.3 - 34.2)
Silver	ND (<1.54 - <2.15)	ND (<1.44 - <1.6)	ND (<1.69 - <1.89)	NC (<1.62 - 3.21)	ND (<1.67 - <1.94)
Strontium	0.70 (0.62 - 0.87)	0.36 (0.32 - 0.43)	0.53 (0.36 - 0.76)	0.76 (0.40 - 1.12)	0.36 (<0.34 - 0.77)
Tin	9.41 (8.49 - 11.4)	2.90 (<1.45 - 8.4)	4.76 (<1.89 - 7.8)	3.23 (<1.62 - 8.03)	8.20 (4.72 - 18.18)
Vanadium	ND (<1.54 - <2.15)	ND (<1.44 - <1.6)	NC (<1.69 - 3.56)	ND (<1.62 - <1.95)	ND (<1.67 - <1.94)
Zinc	133 (105 - 158)	94.8 (70.8 - 134)	198 (149 - 231)	130 (95.2 - 149)	154 (131 - 184)

[a] ND = Not detected.
[b] NC = Not calulable.

Table 5. Geometric mean trace element concentrations (µg/g dry weight) in adult waterbird livers from Bowdoin National Wildlife Refuge, 1989. Ranges are shown in parentheses.

Element	American Avocet (n = 5)	Eared Grebe (n = 5)	American Coot (n = 5)	Northern Shoveler (n = 5)	Ruddy Duck (n = 5)
Aluminum	3.65 (<4.3 - 6.1)	ND[a] (<2.9 - <3.2)	3.56 (<3.4 - 6.8)	6.69 (<3.3 - 18.8)	NC[b] (<3.3 - 36.8)
Arsenic	ND (<0.31 - <0.35)	0.35 (<0.31 - 0.6)	NC (<0.34 - 0.76)	ND (<0.32 - <0.34)	NC (<0.34 - 1.0)
Barium	ND (<1.54 - <2.15)	ND (<1.44 - <1.6)	ND (<1.69 - <1.89)	ND (<1.62 - <1.7)	ND (<1.67 - <1.94)
Beryllium	ND (<0.15 - <0.21)	ND (<0.14 - <0.16)	ND (<0.17 - <0.19)	ND (<0.16 - <0.17)	ND (<0.17 - <0.19)
Boron	ND (<1.54 - <2.15)	ND (<1.44 - <1.6)	ND (<1.69 - <1.96)	ND (<1.62 - <1.7)	ND (<1.67 - <1.94)
Cadmium	3.70 (2.01 - 7.08)	2.36 (1.53 - 4.15)	0.69 (0.28 - 2.06)	1.98 (0.86 - 5.97)	1.16 (0.42 - 3.41)
Chromium	0.82 (0.73 - 0.88)	0.34 (<0.31 - 0.66)	0.64 (0.39 - 0.80)	0.91 (0.78 - 1.04)	0.39 (<0.34 - 0.87)
Copper	26.0 (17.7 - 36.9)	19.2 (17.3 - 22.8)	44.5 (20.4 - 66.7)	75.7 (39.3 - 233)	184 (125 - 409)
Iron	1357 (880 - 2380)	2465 (1450 - 3720)	3332 (947 - 8280)	2296 (581 - 5850)	2557 (277 - 6720)
Lead	ND (<0.93 - <1.28)	ND (<0.86 - <0.96)	ND (<1.01 - <1.14)	ND (<0.97 - <1.02)	ND (<1.00 - <1.16)
Magnesium	837 (779 - 903)	666 (633 - 730)	725 (512 - 832)	915 (905 - 942)	815 (692 - 886)
Manganese	15.5 (12.4 - 22.1)	18.9 (14.7 - 22.1)	15.5 (10.4 - 23.9)	23.2 (18.4 - 36.0)	40.3 (22.1 - 223.9)
Mercury	1.21 (0.506 - 3.63)	5.3 (2.82 - 10.5)	0.49 (0.341 - 1.49)	4.16 (1.64 - 8.86)	0.98 (0.406 - 2.59)
Molybdenum	2.94 (2.34 - 3.98)	1.73 (<1.53 - 2.68)	4.71 (2.92 - 8.04)	5.14 (3.75 - 8.88)	4.75 (3.43 - 7.46)

Table 6. Geometric mean trace element concentrations (µg/g dry weight) in waterbird eggs from Bowdoin National Wildlife Refuge, 1989. Ranges are shown in parentheses.

Element	American Avocet (n = 12)	Eared Grebe (n = 13)	American Coot (n = 17)	Northern Shoveler (n = 9)	Gadwall (n = 10)	Ruddy Duck (n = 7)
Aluminum	ND[a] (<30 - <30)	NC[b] (<30 - 64.4)	NC (<30 - 43.3)	ND (<30 - <30)	NC (<30 - 58.2)	ND (<30 - <30)
Arsenic	ND (<0.2 - <0.2)	NC (<0.2 - 0.442)	NC (<0.2 - 1.15)	ND (<0.2 - <0.2)	ND (<0.2 - <0.2)	ND (<0.2 - <0.2)
Barium	1.31 (<1 - 4.53)	NC (<1 - 2.05)	2.77 (<1 - 13.1)	1.70 (<1 - 12.0)	1.78 (<1 - 3.43)	5.58 (2.31 - 23.1)
Beryllium	ND (<0.2 - <0.2)	NC (<0.2 - 0.23)	NC (<0.2 - 0.61)	ND (<0.2 - <0.2)	ND (<0.2 - <0.2)	ND (<0.2 - <0.2)
Boron	NC (<2 - 3.95)	NC (<2 - 5.23)	2.66 (<2 - 7.83)	ND (<2 - <2)	3.48 (<2 - 7.48)	ND (<2 - <2)
Cadmium	ND (<0.5 - <0.5)	ND (<0.5 - <0.5)	ND (<0.5 - <0.5)	ND (<0.5 - <0.5)	ND (<0.5 - <0.5)	ND (<0.5 - <0.5)
Chromium	ND (<3 - <3)	ND (<3 - <3)	NC (<3 - 4.14)	ND (<3 - <3)	ND (<3 - <3)	ND (<3 - <3)
Copper	3.06 (<3 - 5.77)	NC (<3 - 5.04)	3.35 (<3 - 6.0)	2.42 (<3 - 4.33)	3.78 (<3 - 6.05)	4.28 (3.74 - 4.90)
Iron	124 (99 - 200)	159 (120 - 212)	131 (63 - 266)	117 (66 - 267)	127 (87 - 274)	149 (133 - 215)
Lead	ND (<5 - <5)	ND (<5 - <5)	NC (<5 - 5.15)	ND (<5 - <5)	ND (<5 - <5)	ND (<5 - <5)
Magnesium	496 (384 - 633)	528 (397 - 776)	635 (442 - 835)	405 (299 - 526)	494 (413 - 587)	344 (278 - 376)
Manganese	3.56 (2.25 - 5.92)	4.06 (2.7 - 10.0)	3.51 (<1.5 - 7.53)	2.35 (<1.5 - 5.36)	2.28 (<1.5 - 4.57)	2.46 (1.59 - 3.59)
Mercury	0.486 (0.237 - 1.76)	0.307 (0.204 - 0.411)	0.343 (0.234 - 1.22)	0.750 (0.296 - 3.08)	0.118 (0.053 - 0.321)	0.065 (0.031 - 0.175)
Molybdenum	ND (<7 - <7)	ND (<7 - <7)	ND (<7 - <7)	ND (<7 - <7)	ND (<7 - <7)	ND (<7 - <7)

Table 6. (cont.)

Element	American Avocet (n = 12)	Eared Grebe (n = 13)	American Coot (n = 17)	Northern Shoveler (n = 9)	Gadwall (n = 10)	Ruddy Duck (n = 7)
Nickel	ND (<3.5 - <3.5)	ND (<3.5 - <3.5)	ND (<3.5 - <3.5)	ND (<3.5 - <3.5)	ND (<3.5 - <3.5)	ND (<3.5 - <3.5)
Selenium	2.68 (1.78 - 4.32)	4.22 (2.39 - 6.42)	1.49 (0.79 - 1.89)	2.19 (1.6 - 3.81)	1.94 (1.42 - 2.63)	2.58 (2.07 - 3.08)
Silver	ND (<10 - <10)	ND (<10 - <10)	ND (<10 - <10)	ND (<10 - <10)	ND (<10 - <10)	ND (<10 - <10)
Strontium	13.57 (8.57 - 23.1)	15.02 (8.87 - 23.4)	16.29 (9.26 - 41.4)	18.67 (14.3 - 24.5)	15.68 (8.68 - 31.4)	13.00 (8.89 - 27.4)
Tin	ND (<30 - <30)	ND (<30 - <30)	ND (<30 - <30)	ND (<30 - <30)	ND (<30 - <30)	ND (<30 - <30)
Vanadium	ND (<1.5 - <1.5)	ND (<1.5 - <1.5)	ND (<1.5 - <1.5)	ND (<1.5 - <1.5)	ND (<1.5 - <1.5)	ND (<1.5 - <1.5)
Zinc	50.8 (40.0 - 71.7)	58.2 (46.6 - 71.5)	65.8 (51.7 - 85.6)	61.3 (42.8 - 74.2)	66.9 (49.4 - 91.9)	54.0 (49.4 - 62.3)

[a] ND = Not detected.
[b] NC = Not calulable.

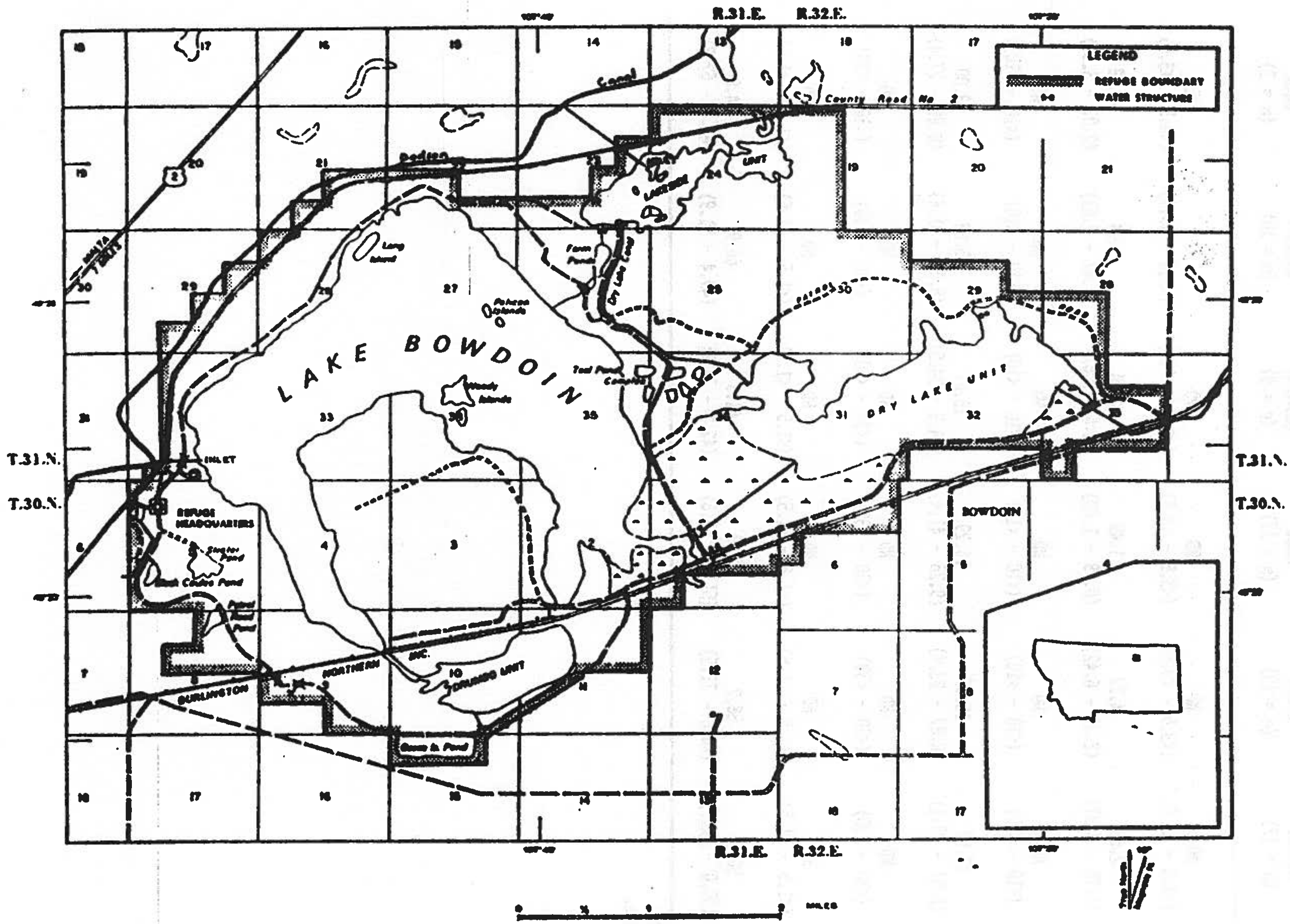


Figure 1. Bowdoin National Wildlife Refuge, north-eastern Montana, 1989.

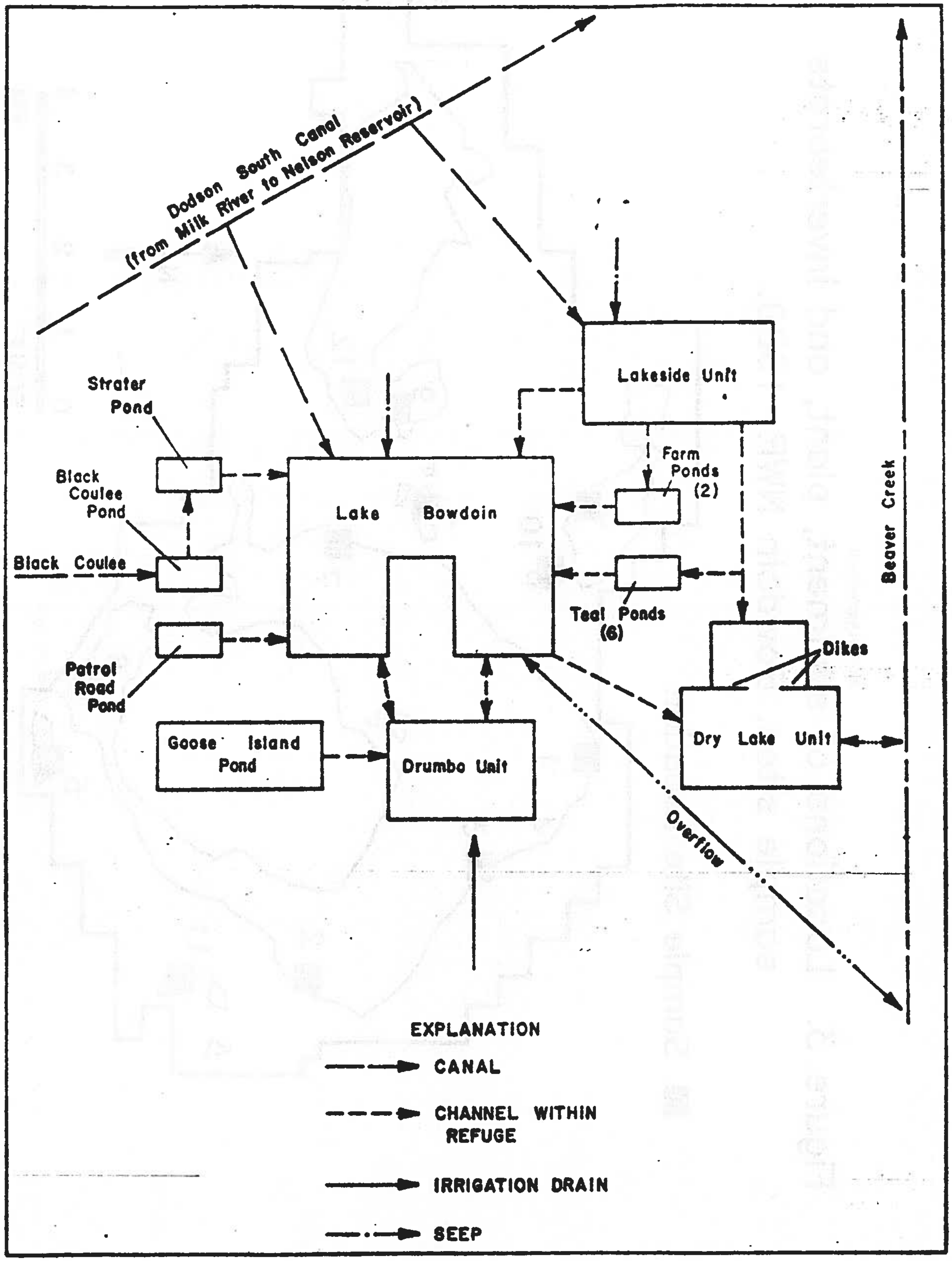


Figure 2. Schematic diagram of the water system at Bowdoin National Wildlife Refuge (from Lambing et al. 1988).

Figure 3. Locations of sediment, plant, and invertebrate sample sites, Bowdoin NWR, 1989.

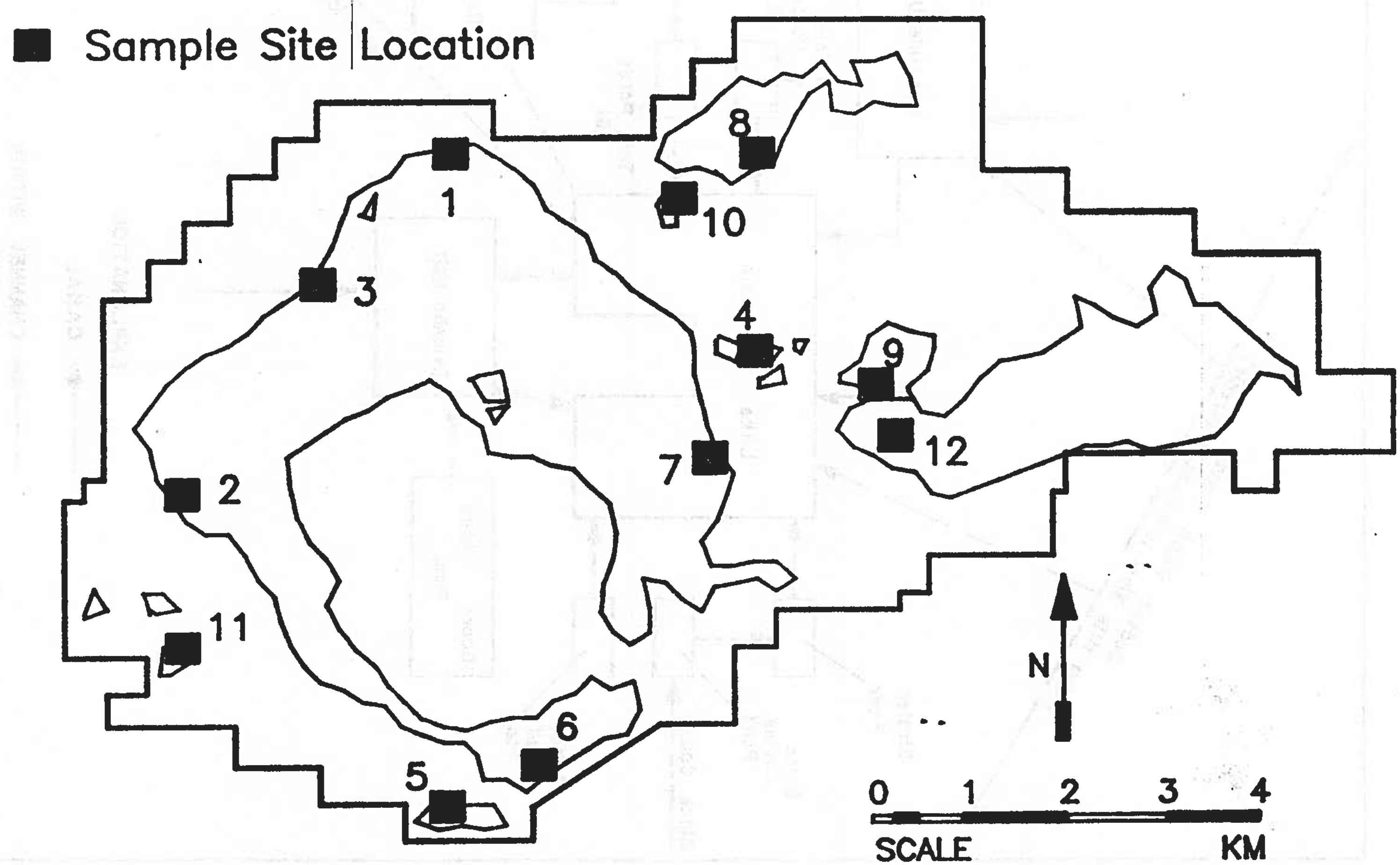


Figure 4. Locations of American Avocet adults and eggs collected at Bowdoin NWR, 1989.

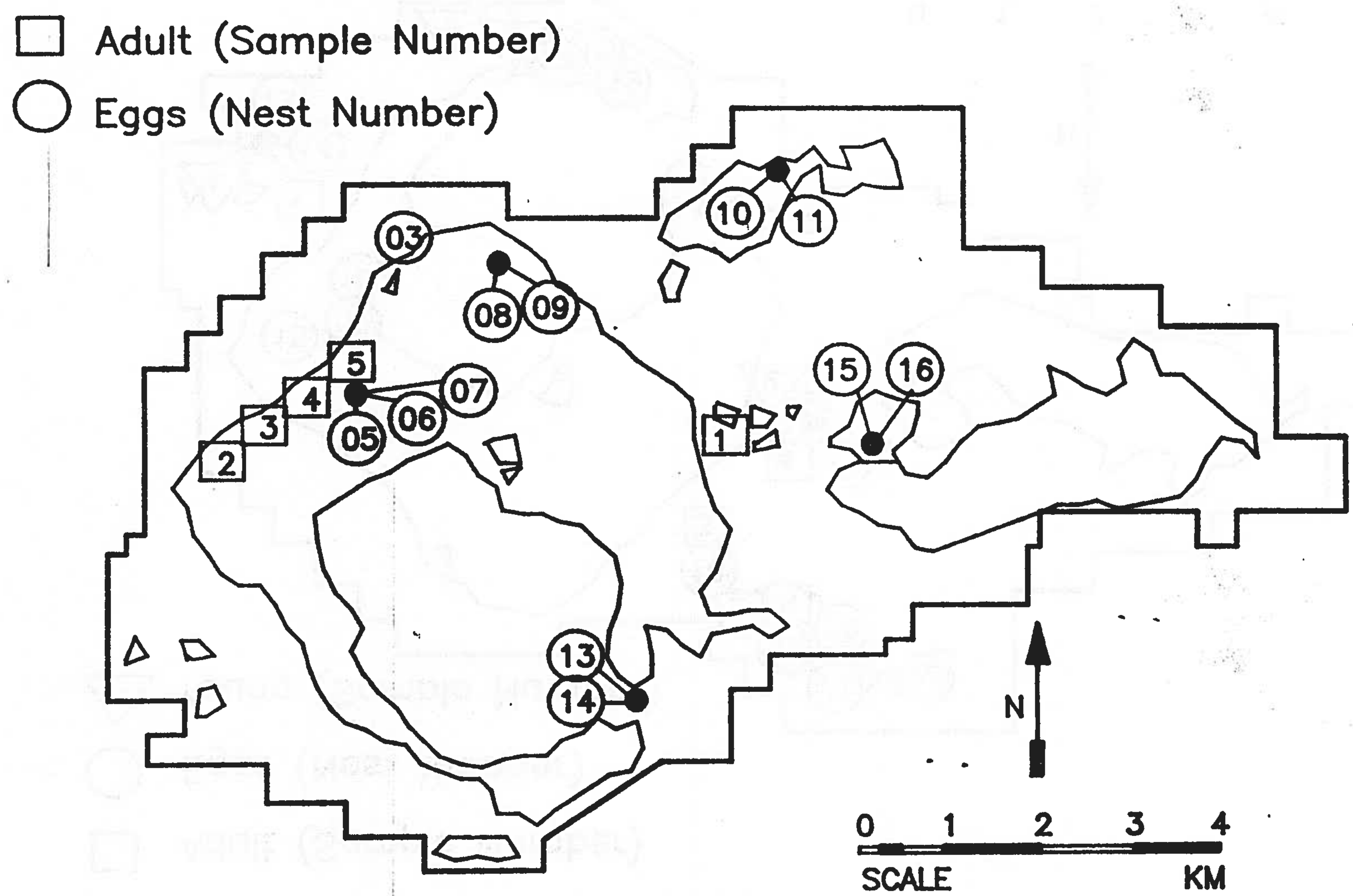


Figure 5. Locations of American Coot adults, eggs, and young collected at Bowdoin NWR, 1989.

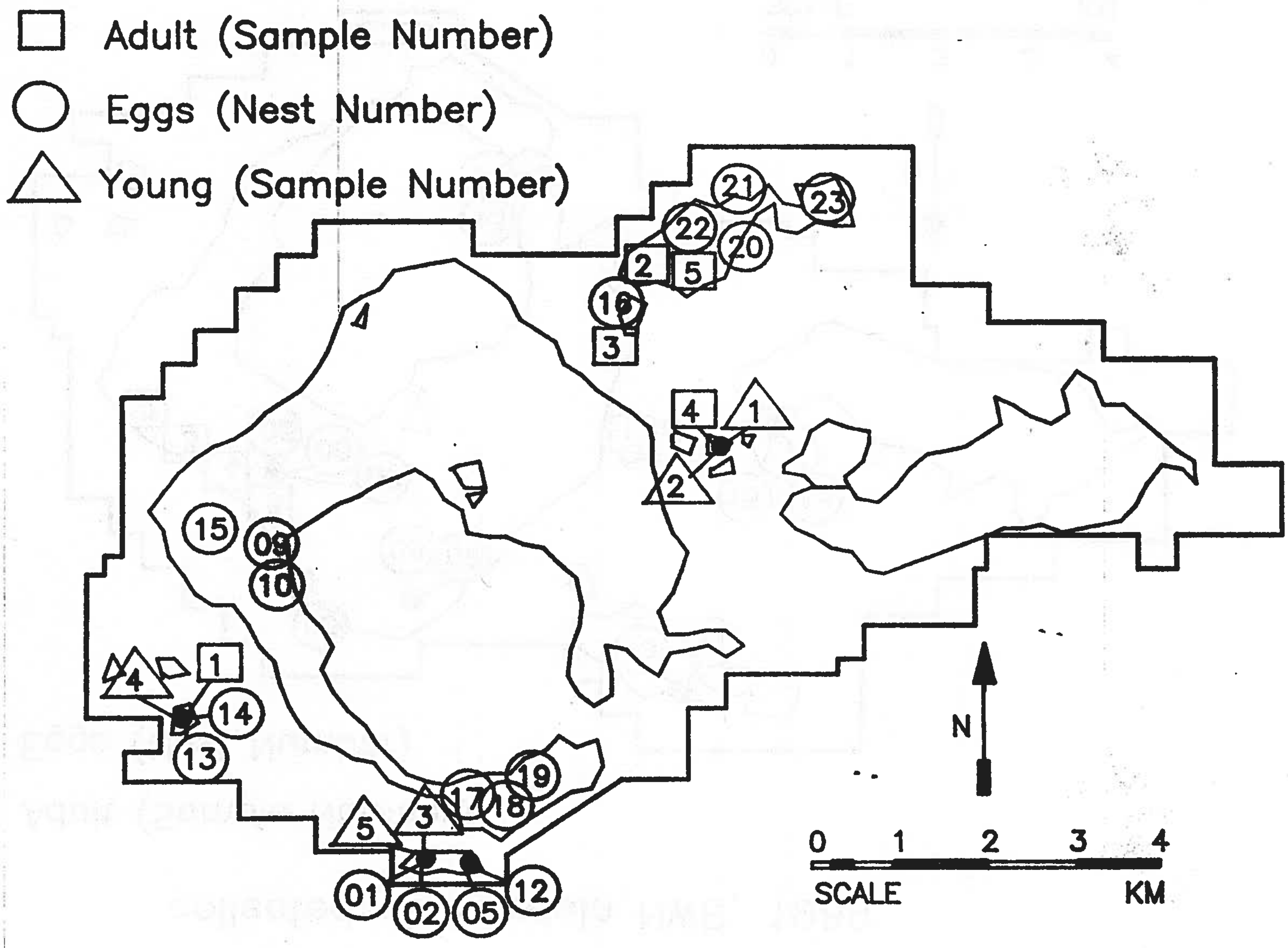


Figure 6. Locations of Eared Grebe adults, eggs, and young collected at Bowdoin NWR, 1989.

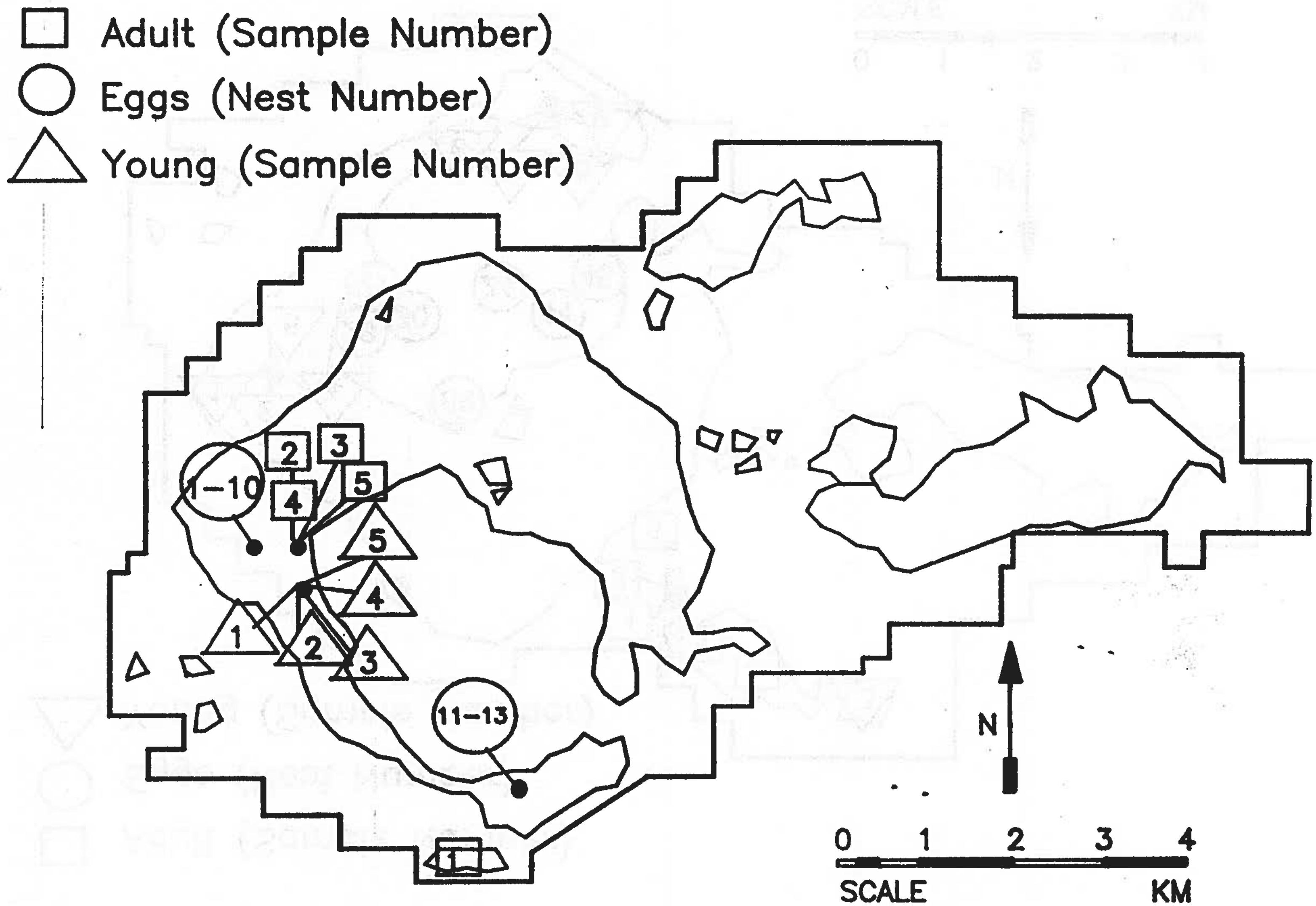


Figure 7. Locations of Northern Shoveler adults, eggs, and young collected at Bowdoin NWR, 1989.

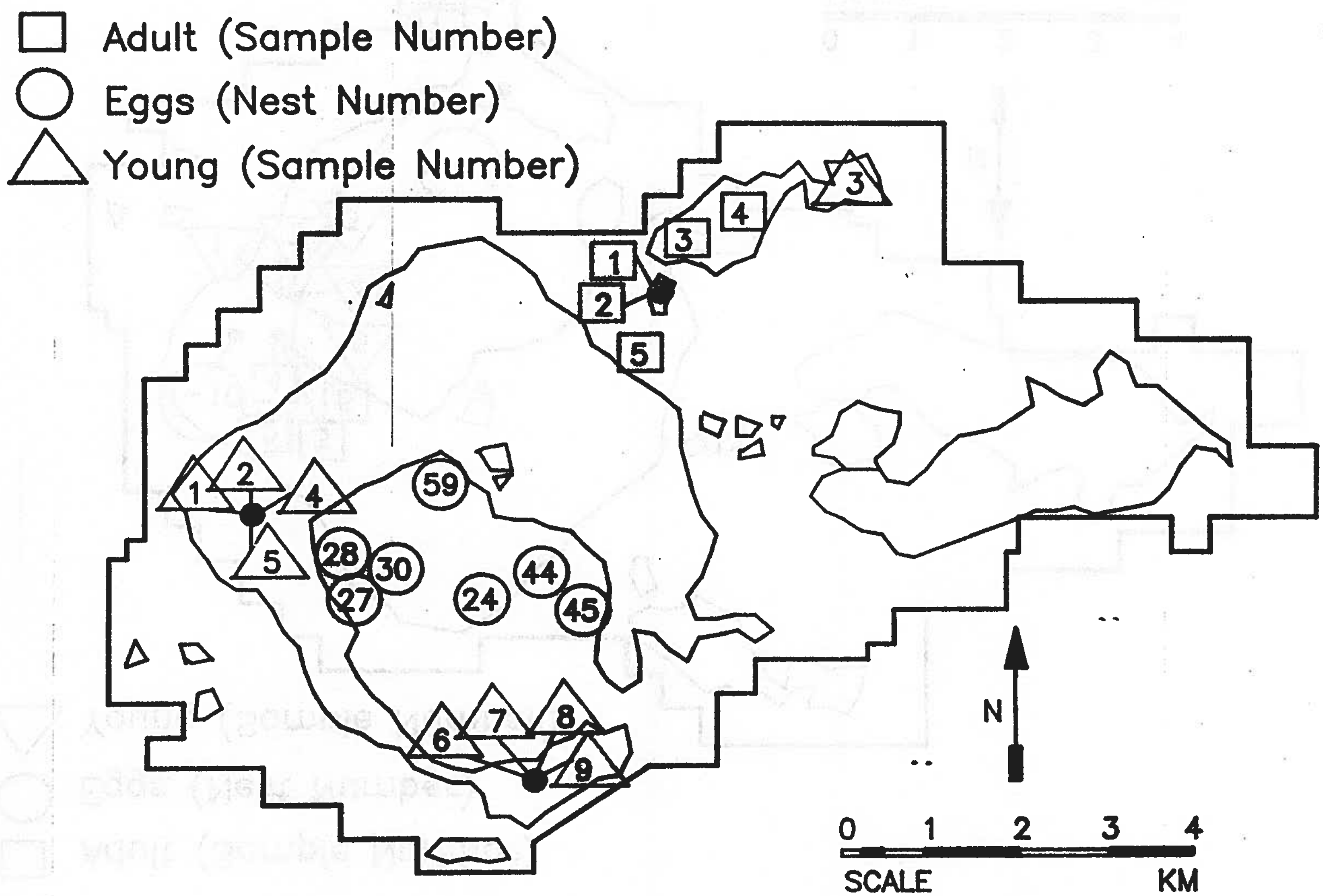


Figure 8. Locations of Gadwall eggs collected at Bowdoin NWR, 1989.

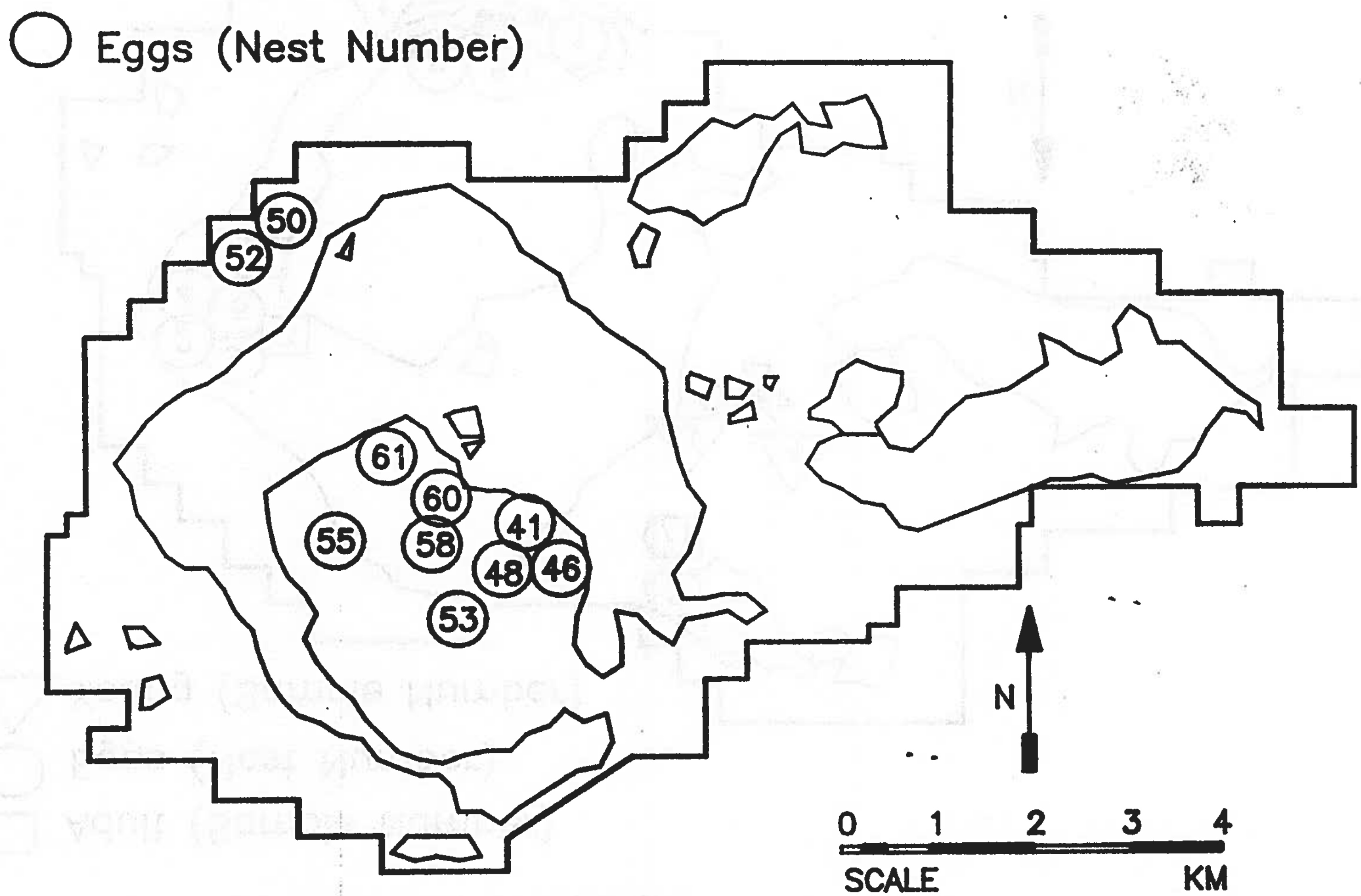


Figure 9. Locations of Ruddy Duck adults, eggs, and young collected at Bowdoin NWR, 1989.

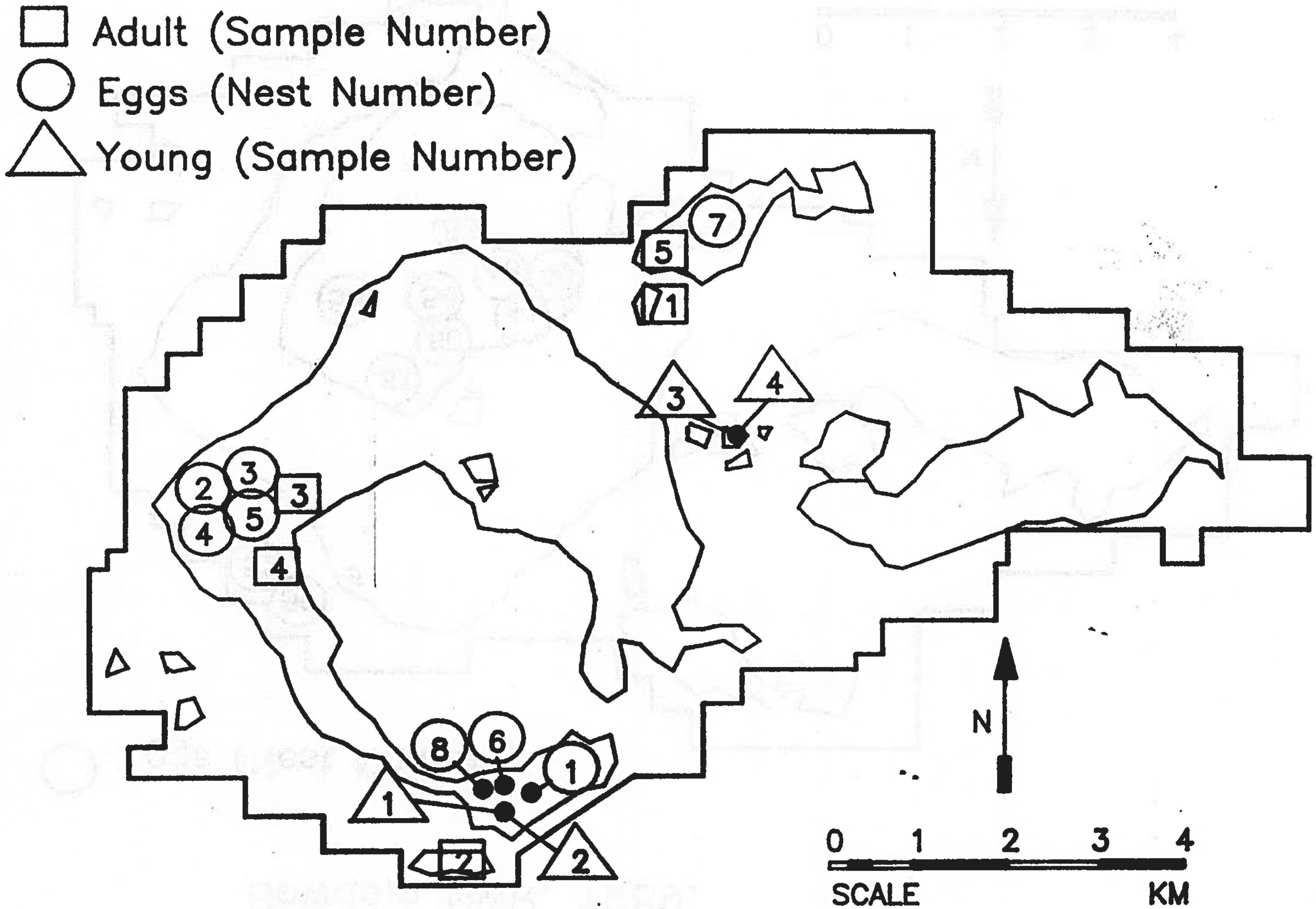
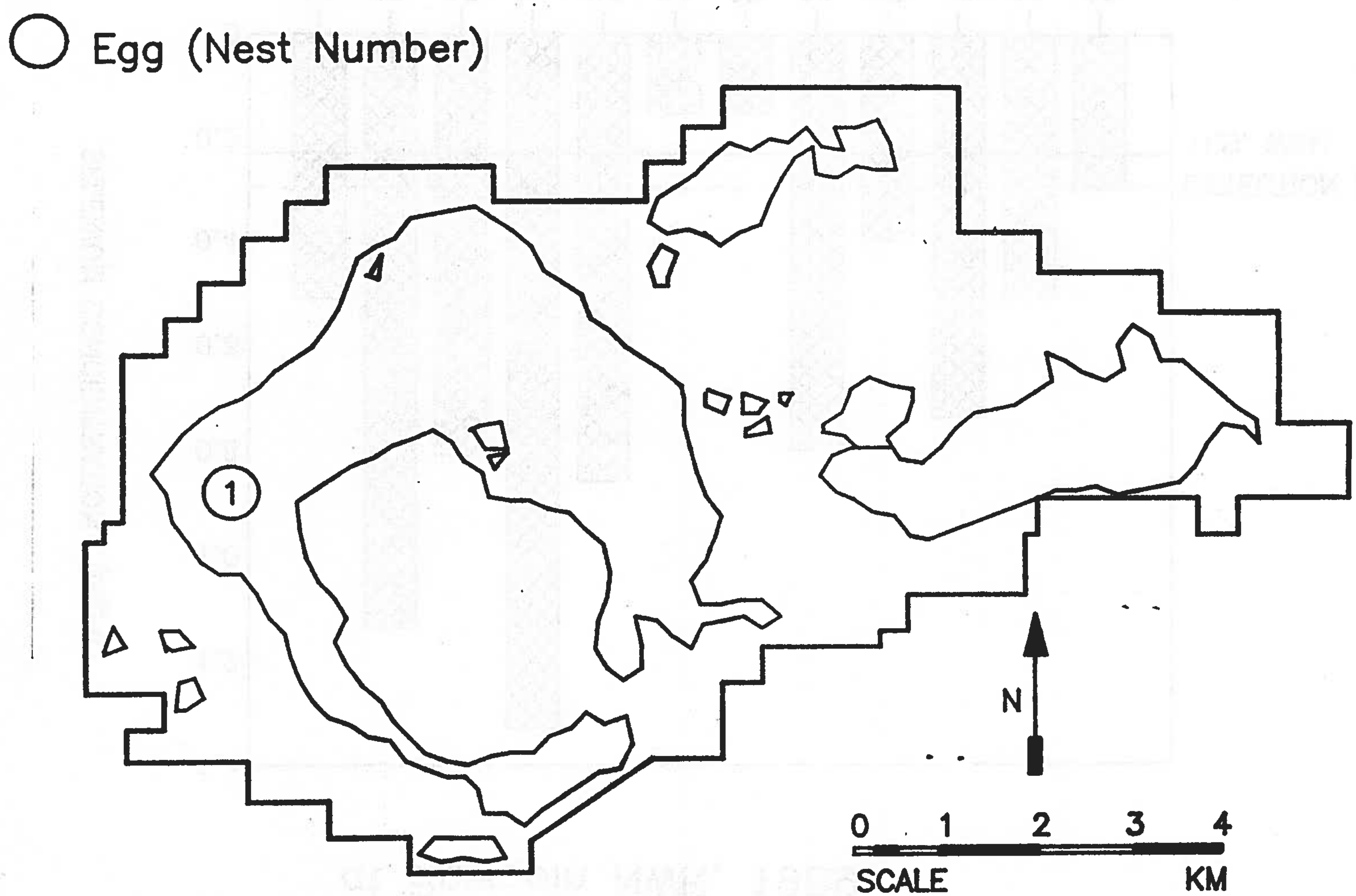


Figure 10. Location of White-faced ibis egg collected at Bowdoin NWR, 1989.



52

Figure 11. Selenium levels in sediment samples collected at Bowdoin NWR, 1989.